CORRESPONDENCE

The Probing of the Tropopause by Balloons that Follow It—A Suggestion [1]

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Over a half century after the discovery of its existence, the tropopause is still one of the challenging mysteries to meteorologists. Radiosonde observations indicate that the vertical temperature gradient of the air often changes rather abruptly at the tropopause, although the apparent sharp break of the temperature gradient may be artificial because of the fact that straight line segments between reported temperature observations are employed to represent the true, and perhaps smoother, temperature distribution. Even if the kink of the temperature curve at the tropopause is removed, the fact remains that the temperature gradient changes rapidly within a rather narrow zone immediately above and below the point designated as the tropopause. The mystery about the tropopause is, therefore, not primarily its location, but rather the sharpness of the change of the temperature gradient that is associated with it. The radiative processes and the other large-scale heat transport processes that determine the mean atmospheric temperature distribution probably also determine the large-scale features of the tropopause, such as its general location and its seasonal and large-scale spatial variations. But what is the reason for the often observed sharp change of the temperature gradient at the tropopause? What are the physical processes that are responsible for its creation, maintenance, transformation, and destruction?

There are as yet no answers to these questions. Few suggestions concerning the creation of a sharp tropopause or its maintenance have been put forward (i.e. Möller [5], Staley [8], Kaplan [3]) and they are hypothetical in that they are based on other assumptions.

Still more basic and serious than this, it seems to this writer, is the fact that we do not even have an adequate observational study of the tropopause. We have only a gross and simplified picture of the tropopause and we do not know how a particular tropopause evolves with time.

There are several reasons why ordinary radiosonde observations fail to provide a detailed picture of the tropopause. First of all, the ordinary practice of reporting alternatively the humidity and temperature prohibits a continuous description of temperature. Second, as a result of the combined effect of the large ascensional rate of the balloon and the time lag of the sensing thermistor, the reported temperature actually represents an average temperature over a rather large distance in the vertical below the location of the reported temperature.[2] In addition, the representation of the temperature transmission in each baroswitch contact by a short trace on the recording paper often makes it undesirable to obtain more than one or two temperature readings in each baroswitch contact. At the 200-mb. level, which is about the level of the tropopause at middle latitudes, each contact represents a vertical distance of about 450 feet. Therefore, the maximum meaningful information that one may derive from the ordinary radiosonde is about one or two temperature readings for every 450 feet at the tropopause layer. This is not enough to delineate the detailed structure of the tropopause.

Equally as important as information about the detailed structure of the tropopause at one particular moment, is knowledge of the evolution of the same tropopause with time. Efforts to follow the life history of a tropopause have met with little success due to the fact that the observations now available at fixed locations are not meant and are not suitable for this kind of study. Only by following and making observations of one and the same tropopause, can the life history of the tropopause be ascertained.

In view of the above inadequacies of the present radiosonde system, it is hereby suggested that instrumented constant level balloons be employed to follow and to probe the tropopause. This suggestion was prompted by the following two observations:

1. At both low and high latitudes the tropopause is often well defined and coincides with the minimum temperature. It seems, therefore, that the tropopause is a continuous surface of minimum temperature with considerable horizontal extent at those latitudes.

2. In the last decade or so, constant level balloons have been successfully used to probe the air flow of upper troposphere or lower stratosphere (Moore, Smith, and Gaalswyk [6], Neiburger and Angell [7]). The balloons were set to float along a certain isobaric surface.

If the tropopause is a surface of minimum temperature, then in principle it should be possible to set the balloons to stay and to float at this surface of minimum temperature. This can be done, for example, by having a series of simultaneous temperature observations (3 or more) from thermistors attached an equal distance apart on a line dangling from the balloon, and by having the floating level of the balloon regulated by the requirement that the middle thermistor should register the minimum temperature.[3] If due to the ascending or descending of

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[2] For one type of U.S. radiosonde, the vertical distance of averaging is estimated to be no less than 350 feet (Chiu [1]).

[3] Since the balloon package is floating with the air, an aspirator would be necessary to keep each of the temperature sensing elements ventilated in order to prevent radiation errors.

the balloons this requirement is not met, then the comparison between the temperature registered by the middle thermistor and its immediate neighboring thermistors will set a mechanism into operation (e.g., the dropping of the ballast or the releasing of the gas from the balloon) to bring the balloon up or down to the desired level. In this manner it should be possible to control the balloon, causing it to float and to oscillate about the tropopause with a certain preset limit (this limit is determined by the spacing between the thermistors and by the sensitivity of the height control mechanism).

The above described observations, if successful, could provide us with a detailed temperature structure of the tropopause layer (a tropopause layer is here interpreted as meaning a layer of certain thickness in which the tropopause is found).[4] There are many other useful pieces of information which we should like to have. For example, if the humidity can be measured with certain desired accuracy then we may replace all the thermistors in the above experiment by humidity elements and get a detailed structure of the vertical humidity distribution. The importance of this kind of information is obvious. The difficulty is, of course, whether equipment can be found which will measure the humidity with adequate accuracy at the tropopause level.

Another very useful piece of information that might be obtained from the floating balloons is the heating or cooling of air in the tropopause layer by radiative processes. This may be done, for example, by installing three of Suomi's [9] net radiometers at, above, and below the tropopause. From these measurements the divergence of radiative flux, and therefore the temperature change, above and below the tropopause could be easily calculated. In this way it might be possible to see just how the radiative processes are affecting the detailed structure of the tropopause, providing that the balloons are traveling with the same air parcel.

It is also possible that the radiation measurements at the tropopause may be used to settle one of the very important questions about the tropopause; i.e., is the tropopause a material surface?[5] By material surface is meant one consisting of the same air particles as time progresses. If the tropopause is a material surface and the ballon follows the horizontal motion of the air, then the balloon will stay in the same parcel of air as it travels. In that case there should be no advection of heat into the temperature sensing elements. The change of the potential temperature registered by the thermistors would then be mainly due to radiative processes. By comparing the measured potential temperature changes from the radiometers, on the one hand, and those from the thermistors, on the other, it should be possible then to ascertain whether or not the tropopause is a material surface.

An alternate scheme of carrying out the observation is to set the balloon to float freely near the tropopause. This scheme was suggested to the writer by the Air Force balloon design and operation groups at Geophysics Research Directorate, Bedford, Mass., when they were consulted on the balloon flight problem. According to three people [10], "the balloon could support a line about 2,000 feet long beneath it, with thermistors spaced at appropriate intervals along the line. The balloon could be set to float at or just below the expected height of the tropopause, and its altitude could be adjusted upward in small increments by the dropping of ballast." In this way, there is a fair chance that the line dangling from the balloon will traverse the tropopause.

At this stage, the suggested new technique of observing the tropopause is only an idea. Funds for its experimentation must be acquired. Much effort then must be made to design and develop the balloon and its instrumentation and to test them in flights. Only after many flight tests can one begin to assess its usefulness. But in view of our meager knowledge about the tropopause, if this correspondence can serve in any way to stimulate interest and effort into the research of the tropopause, then it already has served a very useful purpose.

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[4] According to the people at Instrument Research Laboratory, Geophysics Research Directorate, Bedford, Mass., an encoder-thermistor arrangement is now available that permits up to 25 temperature readings on a 2,000-foot line.

[5] In the literature, opinions both for and against the idea of a material tropopause have been expressed (Lowell [4], Danielsen [2]).